EXAMINING CHANGES IN OZONE OVER THE WESTERN UNITED STATES VIA ASSIMILATION OF SATELLITE OZONE PRODUCTS IN A CHEMISTRY-TRANSPORT MODEL

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Gregory Osterman[1], Jessica Neu[1], Thomas Walker[1], Dejian Fu[1], Susan Kulawik[1,2], and Kevin Bowman[1]

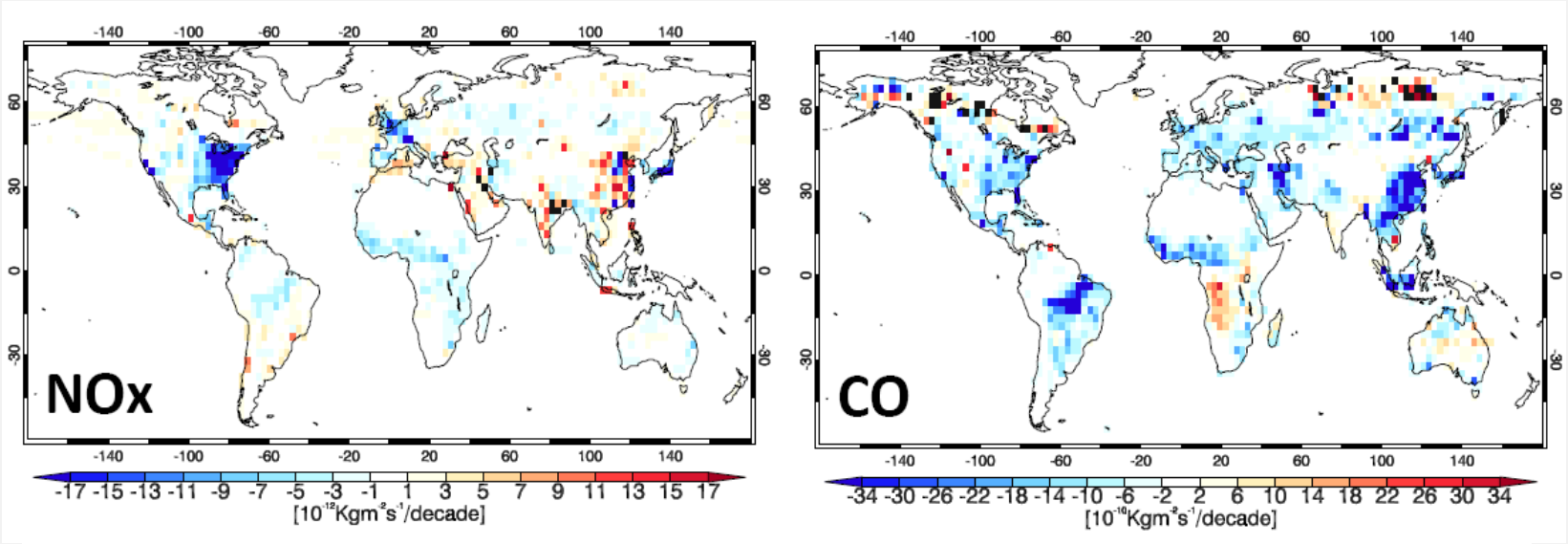
[1]Jet Propulsion Laboratory/California Institute of Technology

[2]Bay Area Environmental Research Institute

CHANGES IN EMISSIONS DURING THE SATELLITE PERIOD

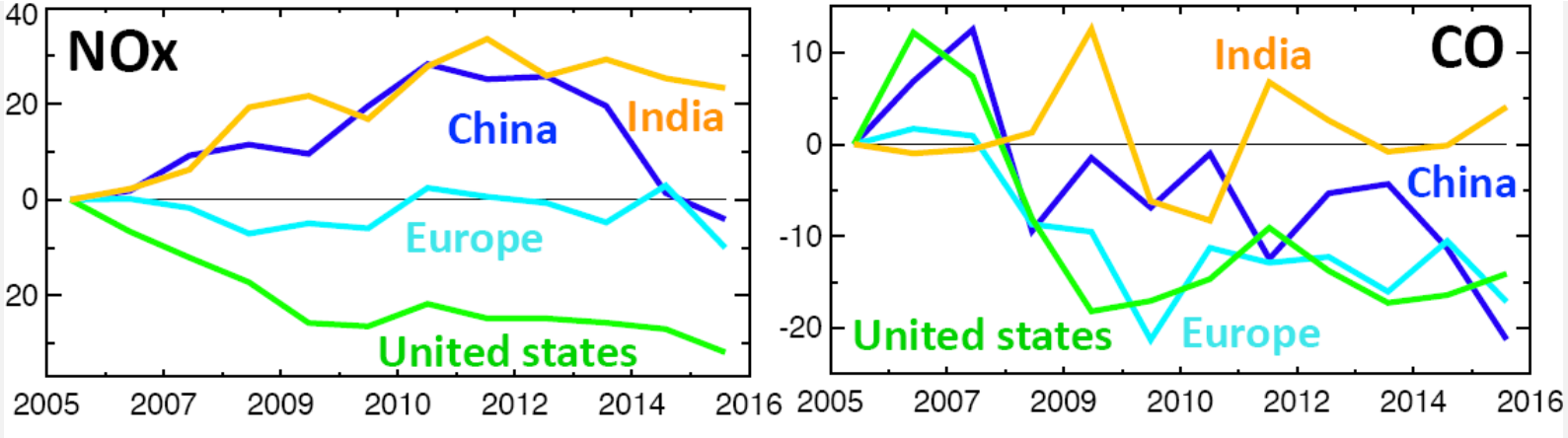
2005-2016 Changes in Emissions based on OMI NO_2 and MOPITT CO

2005-2016 Trend



Figures courtesy of K. Miyazaki

% Difference from 2005



Complex, non-monotonic changes in emissions have occurred during the satellite period, particularly in Asia. What impact have these changes had on tropospheric ozone?

OVERVIEW OF VERSTRAETEN ET AL., 2015 ANALYSIS

Data/Models Used

- Tropospheric Emission Spectrometer (TES) – tropospheric O_3
- Ozone Monitoring Instrument (OMI) – NO_2 tropospheric column
- Microwave Limb Sounder (MLS) – stratospheric O_3
- Tracer Model 5 (TM5) chemistry/transport model
- Top down emissions estimated from OMI NO_2

Conclusions

- Rapid increase in tropospheric O_3 over China (7% in six years) observed by TES
- Model simulations reproduce the observed O_3 increase within uncertainties (taking into account changes in emissions and stratospheric/troposperic exchange)
- Domestic reductions in emissions should have decreased free tropospheric O_3 over the Western US
- Effect is offset by changes in STE and increased transport of O_3 and precursors from Asia.

Limitations of Analysis

- Time period limited to 2005-2010 by TES observations
- No analysis of surface data
- Focus on a broad area of Western US

DRIVERS OF REGIONAL TROPOSPHERIC OZONE CHANGES: 2005-2010

Mid-tropospheric ozone is largely controlled by a combination of emissions, long-range transport, and downward transport from the stratosphere.

Half of the increase in mid-tropospheric ozone over Eastern China from 2005-2010 can be attributed to increasing NO_x emissions, while the other half was associated with natural variability in stratospheric transport.

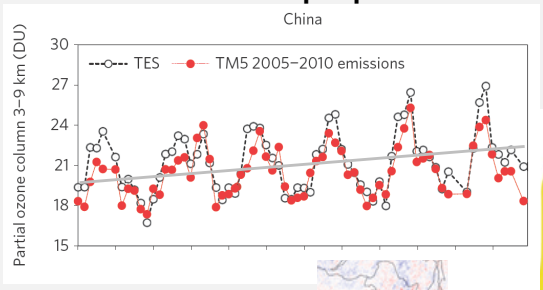
Drivers of Regional Ozone Changes

MLS: Temporary increase in downward transport from the stratosphere partly due to 2009-2010 El Nino.

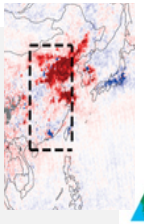
Explains 50% of the ozone increase

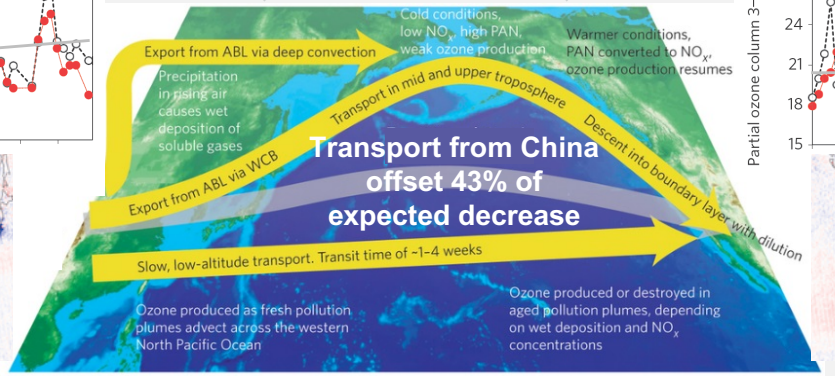
Offset 57% of expected ozone decrease

TES: 7% Increase in mid-tropospheric ozone

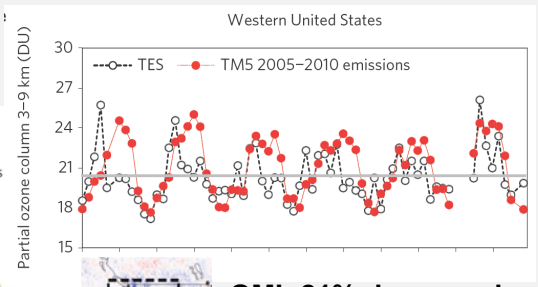


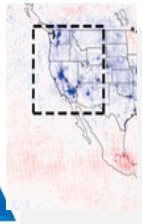
OMI: 21% increase in NO_x emissions. Explains 50% of the ozone increase.





TES: No change in mid-tropospheric ozone





OMI: 21% decrease in NO_x emissions. Should have given a 2% decrease in ozone

Verstraeten et al., 2015; Doherty, 2015

UPDATED ANALYSIS (2017) NEU ET AL. – HAQAST PROPOSAL

Data/Models Used in 2015 Analysis

- Tropospheric Emission Spectrometer (TES) – tropospheric O_3, 2005-2010 only
- Ozone Monitoring Instrument (OMI) – NO_2 tropospheric column
- Microwave Limb Sounder (MLS) – stratospheric O_3
- Tracer Model 5 (TM5) chemistry/transport model
- Top down emissions estimated from OMI NO_2

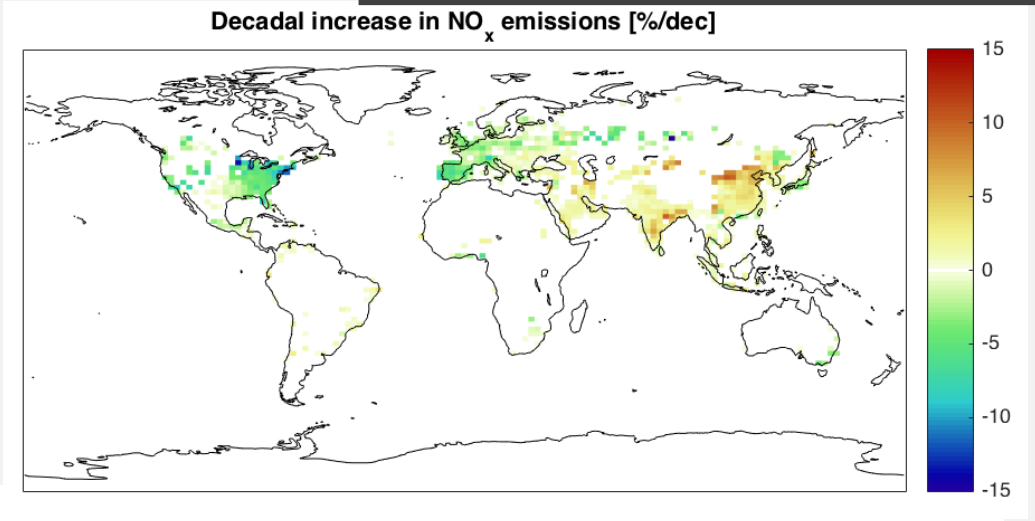
Data/Models Used in 2017 Analysis

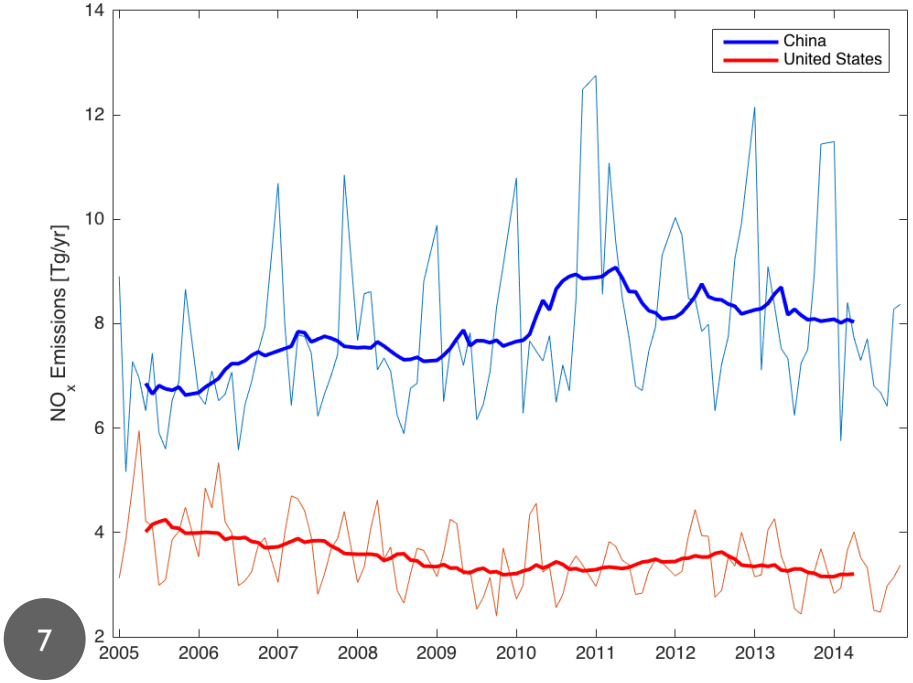
- Tropospheric ozone from combined AIRS/OMI retrievals (2005 – 2015)
- Ozone Monitoring Instrument (OMI) – NO_2 tropospheric column
- Microwave Limb Sounder (MLS) – stratospheric O_3
- GEOS-Chem with satellite data assimilation (MLS stratospheric O_3)
- Updated emissions estimated from satellite data (OMI NO_2)
- Surface ozone data from Western US and Asia

UPDATED ANALYSIS: GEOS-CHEM MODEL SET UP

- GEOS-Chem, v9-01-02 with additional data assimilation capabilities.
  - MLS ozone profiles in stratosphere
  - Uses 3DVAR assimilation approach
- 2° x 2.5° resolution, 47 vertical levels.
- Dynamics driven by MERRA-2 meteorological fields.
- Tropospheric NO_x-HO_x-VOC chemistry.
- LINOZ stratosphere.
- Anthropogenic NO_x emissions as described on following slide
- Other emissions generally from EDGAR v3, overwritten with regional inventories.
- Biomass burning emissions from GFED2.

NO_X EMISSIONS





- Obtained from mass balance inversion of OMI NO_2 columns and GEOS-Chem (similar to Verstraeten et al. 2015).
- Decreases in North America and Europe.
- Top plot shows linear trends over 2005-2015 in % per decade.
- China shows an upward trend: However, emissions in China peak in 2011 and begin to decrease.

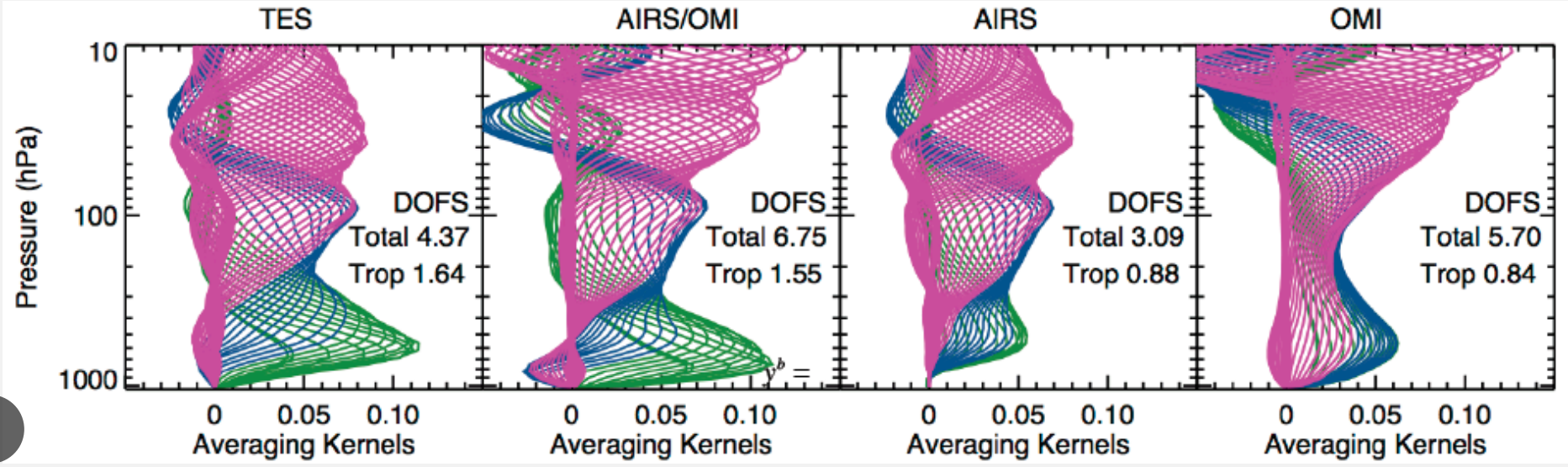
PLANNED MODEL RUNS (2005 – 2015)

1. **Baseline**
   - Mass balance emissions
   - MLS assimilation
2. **Global constant emissions**
   - Constant 2005 emissions globally
   - MLS assimilation
3. **China constant emissions**
   - Constant 2005 emissions over China
   - MLS assimilation
4. **China extrapolated emissions**
   - Mass balance emissions + extrapolated trend over China
   - MLS assimilation
5. **Constant stratosphere**
   - Mass balance emissions
   - Repeated 2005 meteorology and 2005 MLS assimilation

NEW SATELLITE O_3 PRODUCTS: CHARACTERISTICS AND DIAGNOSTICS OF RETRIEVALS

JPL MUSES (MUlti-SpEctra, MUlti-SpEcies, Multi-SEnsors Retrievals of Trace Gases) algorithm delivers both retrieved trace gas concentration profiles and observation operators needed for trend analysis, climate model evaluation, and data assimilation.

Based on TES retrieval algorithm – consistent set of sensitivity metrics and error estimates.



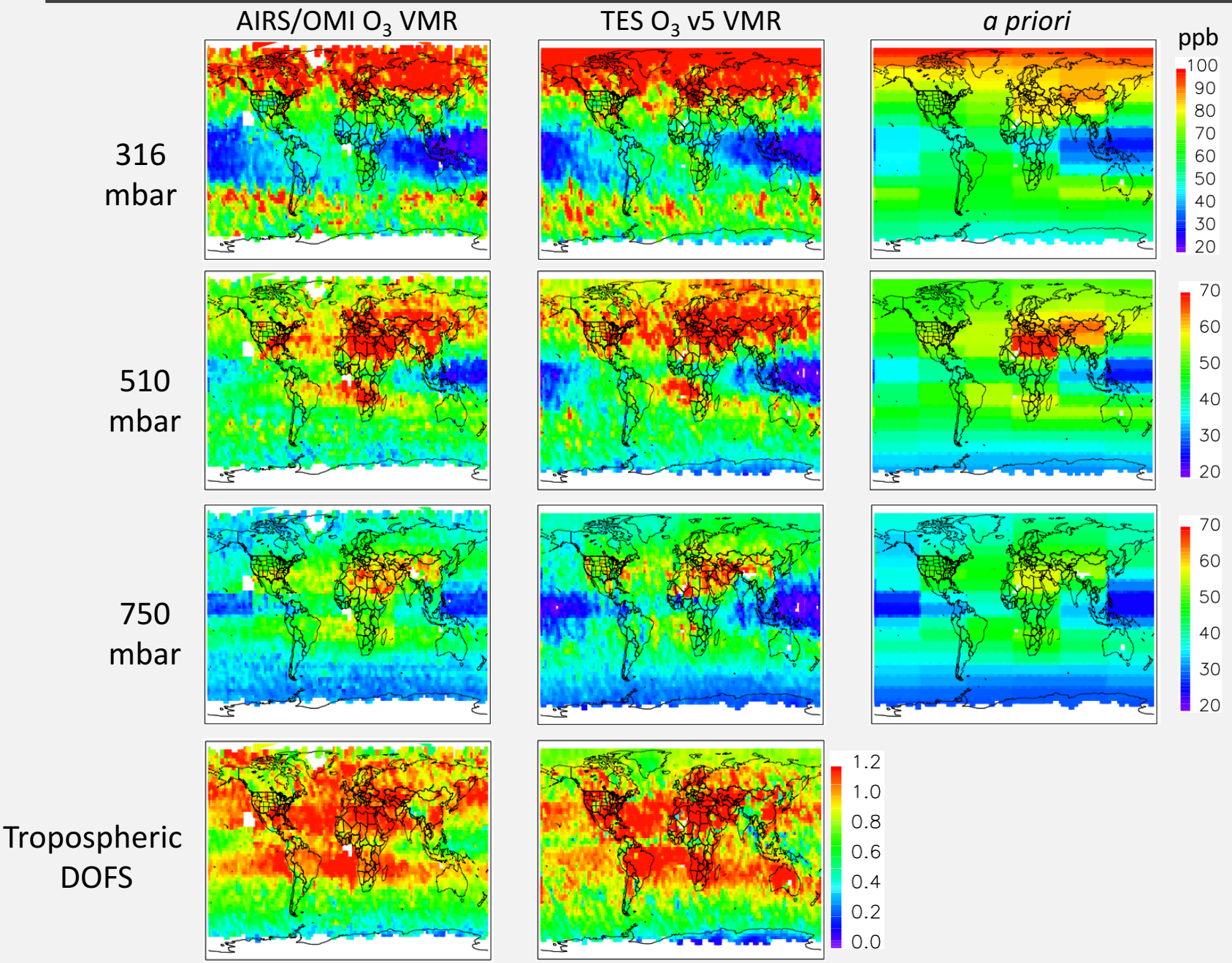
JOINT AIRS/OMI O_3 RETRIEVALS

The AIRS/OMI O_3 retrievals have been configured in two modes.

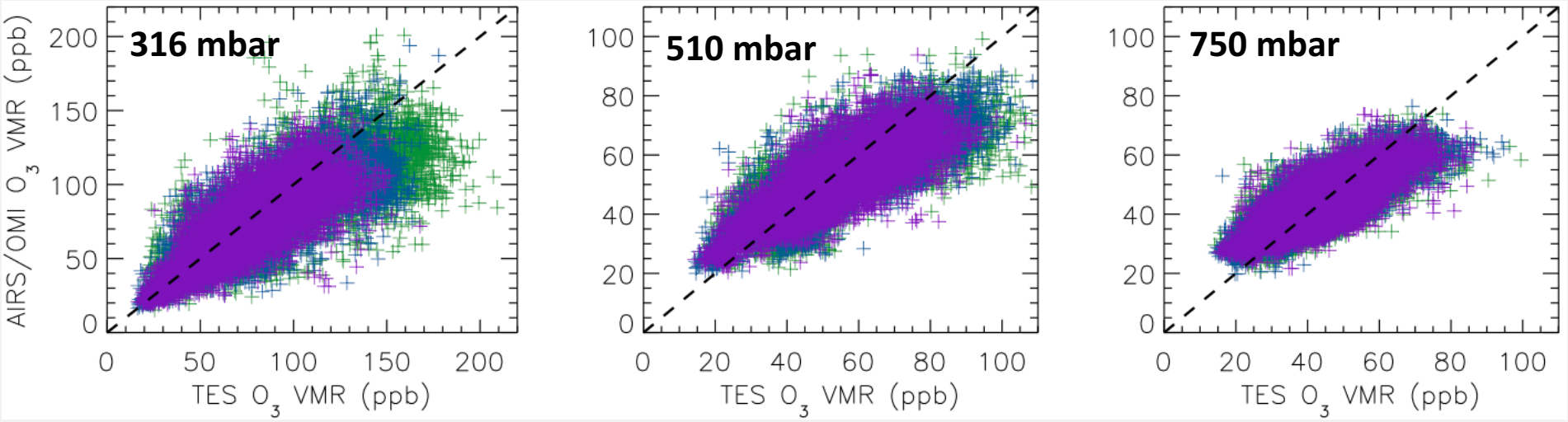
- Global survey mode
  - Provides profile data with a spatial sampling similar to TES global survey
  - 22-month data have been processed including
    - 2006 Jun – Aug
    - 2009 Jan – Jul, Oct – Dec
    - 2010 Jan – May
    - 2016 Mar – Jun
  - December 2017, an estimated release date of AIRS/OMI ozone v1 data
- Regional mapping mode
  - Processes all available measurements for flight campaigns including
    - KORUS-AQ, Apr – Jun 2016
    - ORACLES, Aug, Sept 2016
    - POSIDON, Sept, Oct 2016

Data products have been saved in Hierarchical Data Format, a common format used in the NASA Earth Observation System level 2 products

AIRS/OMI VS. TES V5 GS O_3 PROFILE DATA ON AUGUST 2006



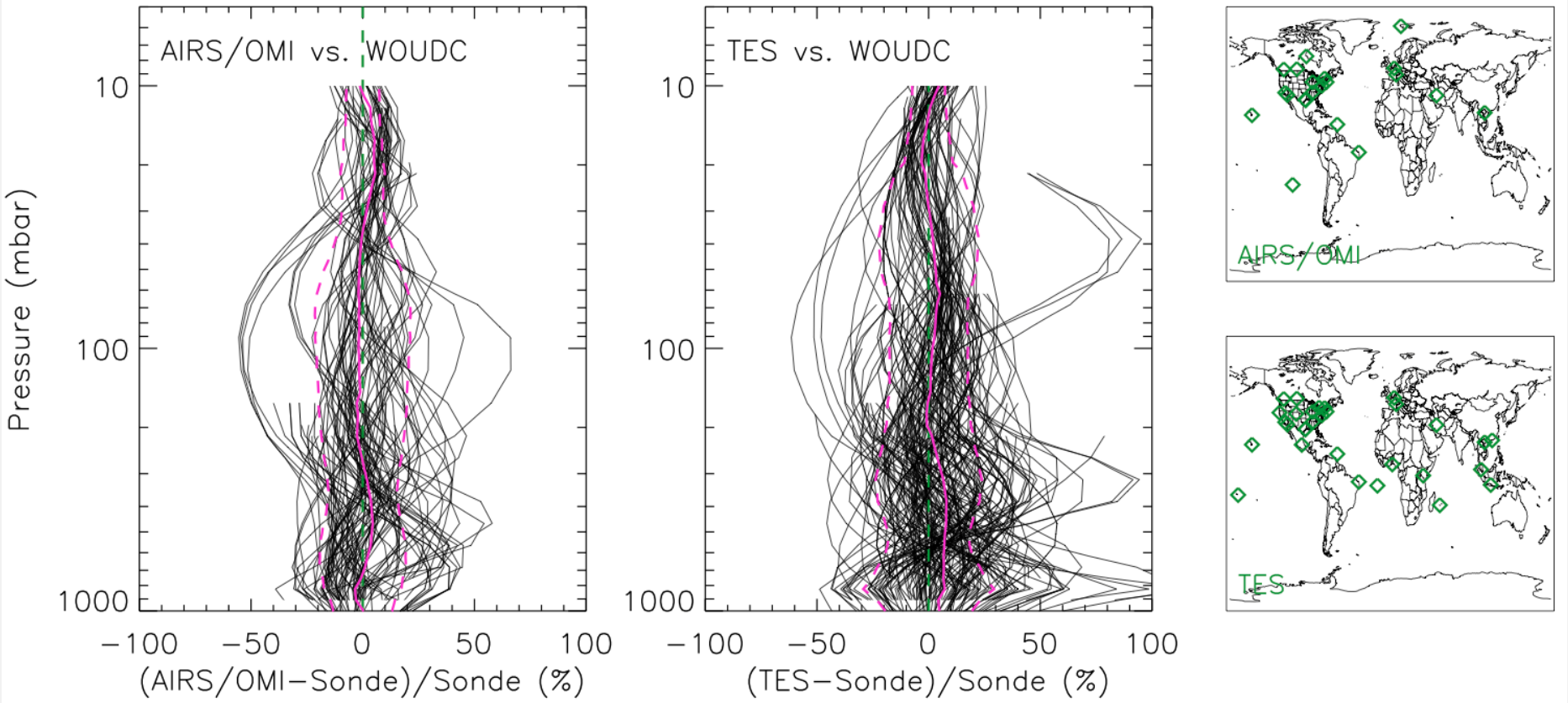
JOINT AIRS/OMI VS. TES GS O_3 DURING SUMMER 2006



- Relative bias < 2-5%. Standard deviation of the differences < the estimated uncertainty.

		316 mbar			510 mbar			750 mbar		
		Jun	Jul	Aug	Jun	Jul	Aug	Jun	Jul	Aug
Correlation Coefficient (r)		0.85	0.85	0.84	0.83	0.82	0.80	0.81	0.77	0.75
Mean Diff. (Joint-TES)	ppb	-7.4	-6.2	-4.0	-3.4	-3.3	-2.9	-1.8	-1.5	-1.8
100 x (Joint-TES)/TES	%	-4.8	-4.4	-3.8	-1.9	-2.1	-2.7	-0.8	-0.4	-1.6
Standard Deviation of Diff.	ppb	20.5	17.7	14.3	10.9	10.0	8.5	7.6	7.3	7.0
100 x (Joint-TES)/TES	%	24.6	22.5	19.5	21.0	19.7	16.8	19.6	19.4	17.9
AIRS/OMI Total Uncertainty	%	27.8	27.8	27.6	22.5	22.5	22.3	24.1	23.9	23.5
TES v5 Total Uncertainty	%	22.0	22.0	22.2	19.5	19.5	19.7	23.9	23.9	23.5

COMPARISONS TO WOUDC OZONESONDES



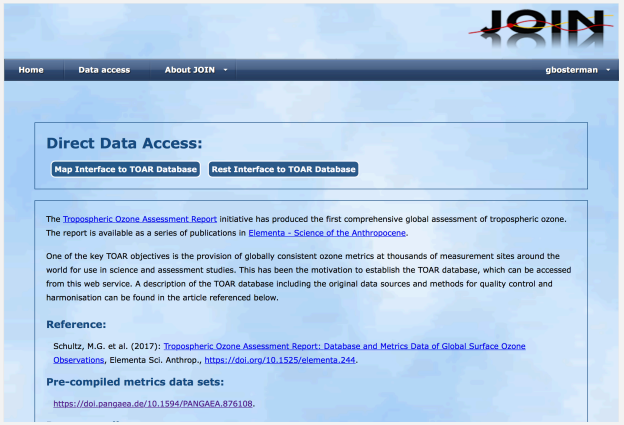
	316 mbar		510 mbar		750 mbar		# of Sites	# of Pairs
	Mean	RMS	Mean	RMS	Mean	RMS		
	100 x (Satellite - Sonde_AppliedAK)/Sonde_AppliedAK							
AIRS/OMI	1.9	15.8	4.0	18.3	-0.7	17.9	21	93
TES	6.6	22.6	7.3	17.9	6.6	22.6	30	171

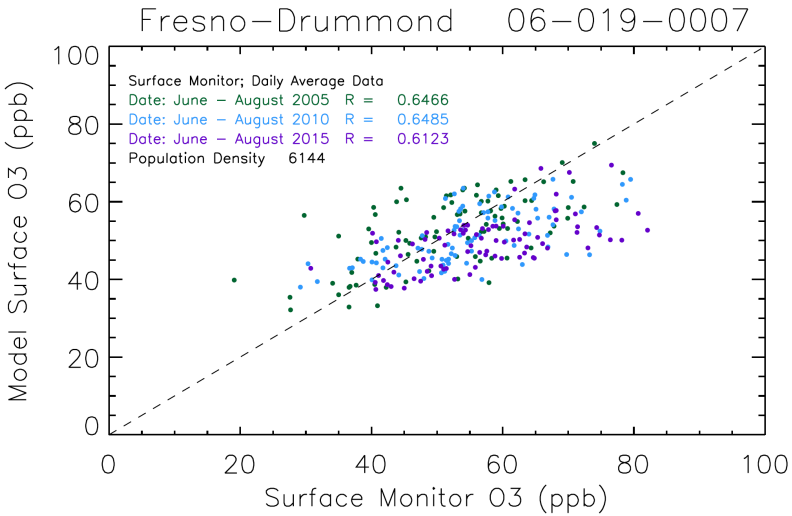
Coincidence criteria

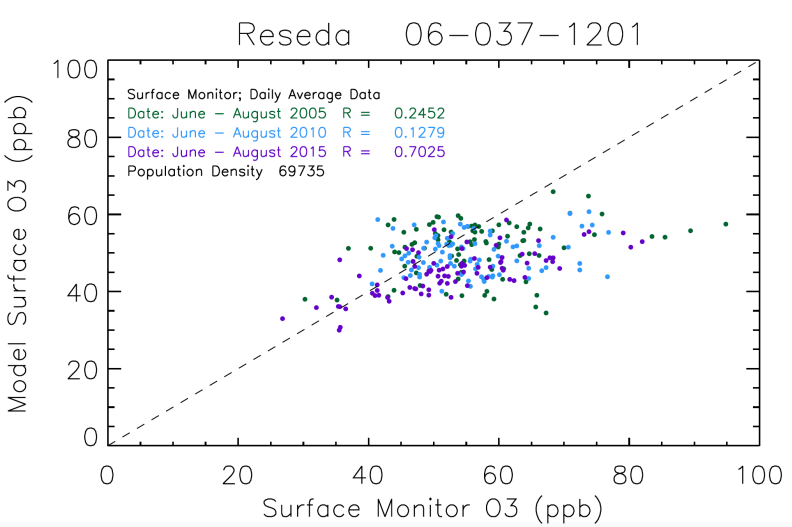
- Passed retrieval quality check
- Distance within 300 km
- Time diff. within 4 hours
- June, July, August 2006

SURFACE DATA COMPARISONS

- Getting ready to start surface data analysis
- Using the TOAR surface monitor database
- Schultz MG, Schröder S, Lyapina O, Cooper O, Galbally I, Petropavlovskikh I, et al.. Tropospheric Ozone Assessment Report: Database and Metrics Data of Global Surface Ozone Observations. Elem Sci Anth. 2017. DOI: http://doi.org/10.1525/elementa.244

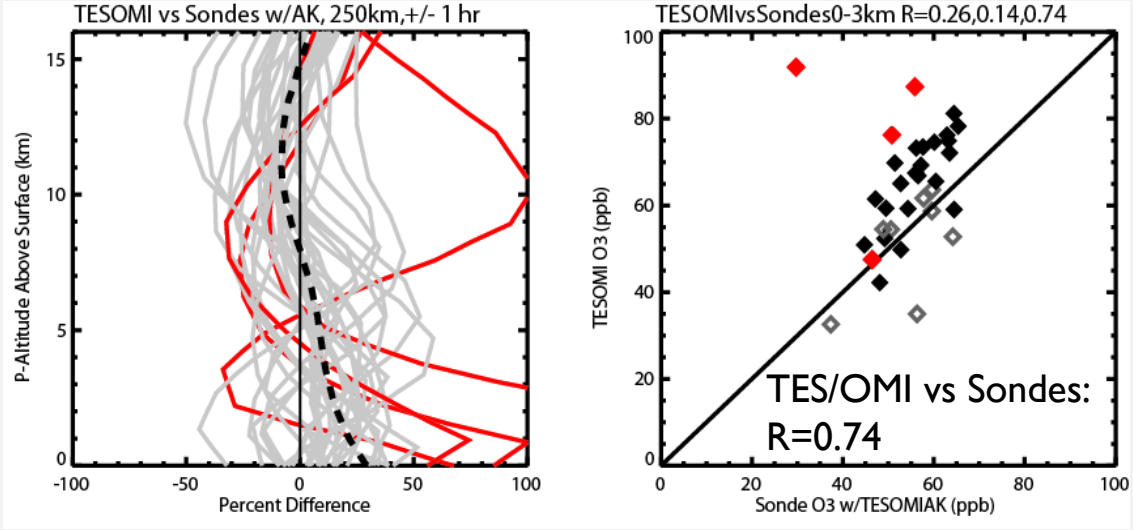


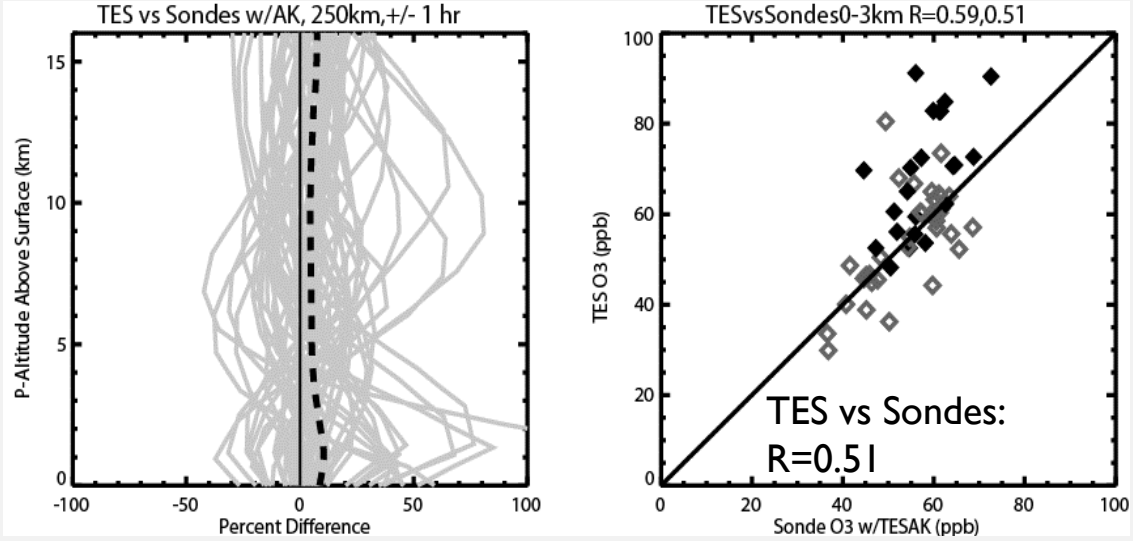




TES/OMI RETRIEVALS

- Another multispectral retrieval product that we can utilize is a combination of TES/OMI radiances
- TES/OMI retrievals have shown improved sensitivity to O_3 in the lowest troposphere over single instrument retrievals
- Provide additional lower tropospheric O_3 information for the 2005-2010 time period
- Validation analysis and paper are currently underway





EXAMINING CHANGES IN OZONE OVER THE WESTERN UNITED STATES VIA ASSIMILATION OF SATELLITE OZONE PRODUCTS IN A CHEMISTRY-TRANSPORT MODEL

- Currently producing GEOS-Chem model runs for analysis
- Validation analysis of combined AIRS/OMI retrievals show that the data can resolve upper and lower tropospheric ozone (similar to TES)
  - The AIRS/OMI data will allow us the ability to extend the Verstraeten et al., 2015 analysis beyond the TES time period
- Utilizing surface data in the analysis to examine how changes in mid-tropospheric ozone affect surface ozone in the model
- Future results:
  - HAQAST Meeting in November 2017
  - AMS Meeting in January 2018